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Active Investment Planning in the Electricity Distribution System

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The investment planning of the distribution network has evolved significantly the emergence of distributed energy resources (DEKs) with generated demand, rapid technological advanced in energy storage system, and rising consumer expectations. Nowadays, planning of active distribution systems (ADS) has been an important issue. There are numerous extensive literatures on ADS planning. This paper reviews the current state of distribution planning. Firstly, traditional investment plans made in Turkey and the approach to ADS are examined, ADS studies conducted in other countries, outputs and case studies are examined. Secondly, the effects of DECs on ADS planning are investigated. The features of ADS planning and the factors affecting ADS are outlined. Finally, it explores some aspects of ADS planning research, including planning within all the elements combined in ADS.

Keywords: *Active distribution system planning (ADS), Distributed energy resources (DERs), Distributed generations (DGs), Integrated planning, İnvestment planning.*

1. Introduction

In order to ensure 24/7 uninterrupted energy supply, and to increase the diversity of resources, renewable energy technology has dramatic increase along with advances in operational practices of distribution system all over the world. Distribution grid faces a difficulty that are more complex and sophisticated in the investment planning model, due to in today's world where high penetrating the number of DERs in the distribution network and development of the low carbon economy. Due to the intermittent and difficult estimation nature of DERs, deterministic methods and a "fit and forget" strategy have always been adopted to cope with integration of variable energy resources. Traditional planning of the distribution grid based on one-way power flow from substation to end -use consumer and projected peak demands.
In this regard, ADS is promoted and perceived as one of the key technologies to alleviate the aforementioned difficulties[1], [2].

With the penetrating use of distributed energy sources (DERs), the disadvantages of these traditional investment methods such as unnecessary network investments, increased network losses, and unachievable development and environmental goals are becoming increasingly evident.
ADS planning is a complex and comprehensive structure that should give both the planning model of the distribution network, and the most economical, reliable and secure allocation of DERs[3].

A shared global definition of active distribution networks (ADNs) was developed by CIGRE C6.19 in 2008: "*Active distribution networks have systems in place to control a combination of DERs, defined as generators, loads and storage*". It is possible for distribution system operators (DSOs) to manage the electricity flows in a flexible network topology. DERs take some degree of responsibility for system support according to a suitable regulatory environment and connection agreement. In 2012 CIGRE conference, CIGRE C6.19 workshop ''planning and optimization methods for active distribution systems'' extended the ADN to active distribution systems (ADS). It highlights that the future distribution grid will not only be a ''network'', but a unified system with some active control approaches for distributed generation, energy storage systems (ESS), electric vehicles (EV) and demand response (DR)[4].

2. Traditional Investment Planning

Traditional distribution planning methods have provided safe and reliable delivery of electricity to consumers. While system is planned, economic conditions, system reliability, safely operate are paid attention in the distribution planning. These assessments are generally in favor of a single decision maker (distribution companies) in decision support. It results in cost-effective reinforcements to address a variety of technical issues with traditional approaches and to keep DERs within operating boundaries[5].

In 1997, the main issues in conventional planning of a power distribution system according to the work of Khator and Leung[2];

- Optimum location of substations according to load and distance
- Route of the feeders
- Optimum individual feeder design
- Optimum load distribution
- Allocation of substation capacity
- Position of transformers relative to substations.

There are 21 distribution companies in Turkey. These companies determine their investment plans every year in line with the needs of the region, within the framework of the rules determined by Republic Of Turkey Energy Market Regulatory Authority (EMRA).
In investments to be made within the scope of investment plans;

- To the safety of life and property
- Continuity of supply and technical quality
- Connection requests to the distribution system.

Priority is given to related investments.
In addition, 5- and 10-year master plans are made for the distribution companies in the short and medium term in a way that foresees the problems that may be encountered in the future, the demand-supply imbalance, expansion or contraction of the distribution system[6].
In 2021, 14.72 billion TL(at current prices) investment was made by distribution companies. According to figure 1, Toroslar with 1.49 Billion TL and Başkent with 1.35 Billion TL are the distribution companies with the highest investment expenditures, respectively.

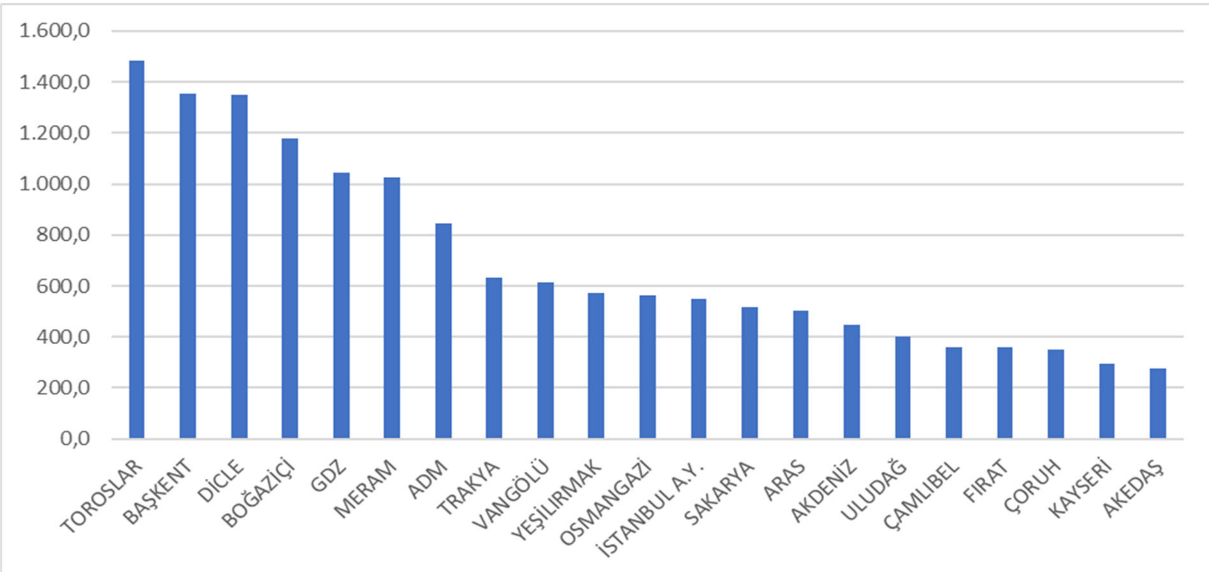

***Figure 1**: Investment expenditures of Distribution Companies in 2021 (Current Prices-Million TL).*

Investment expenditures by investment type in 2021 are shown in the table below. Most of the investments are network investments.

Network investments; Investments regarding all kinds of overhead lines, cables, transformers, switching and lighting facilities used in the facilities and network in the distribution system and all equipment and equipment that form an integral part with them[7].

***Table** 1: Investment Amounts in 2021 by Investment Types (TL).*

Distribution Company	***Investment Type***	***2021 Investment Amount (TL) (CPI June 2021:547,48)***
21 EDAŞ	Network Investments	11.452.407.704
	Investments with Environmental, Security and Other Legal Obligations	1.712.680.394
	Network Operating System Investments	1.273.392.470
	R&D Project Investments	5.804.375
	Other Expenditures as Investment Spending	274.812.694
	Grand Total	**14.719.097.637**

3. Active Investment Planning

Active distribution planning methods are in several respects both more flexible and more sophisticated with respect to their traditional counterparts.
Its most important feature is that it aims to plan with active network management for increasing DG spread by adhering to system operational restrain rather than a "fit-and-forget" approach. The concept of active network management offers new planning concepts, predominantly in modern planning paradigms such as renewable energy resources integration, distributed storage technologies and electric vehicles, supported by communication, smart metering, active demand-side management and advanced distributed automation.
Another important feature of active distribution planning methods is that they can utilize a variety of multi-objective planning techniques to rank viable trade-off solutions among conflicting objectives that satisfy multiple stakeholders[5].

With active investment planning;

- Advanced Prediction and System Modeling

Improved a range of possible futures scenario to reflect the uncertainty in the generation of DERs, more detailed system Load and DER forecasting methods, and DER impacts on the system.

- Hosting Capacity Analysis (HCA)

Mapping the HCA of all circuits provide customers and DER developer on minimal cost location, application and interconnection.

- Disclosure of Network Needs and Location Value

Increasing the transparency of grid needs and publication potential value of deploying DER at specific locations on the grid can decline more expensive grid investments, reduce costs, improve customer relationship and expanding the DER market.

- New Solution Acquisition

Purchasing or procuring DERs from customers and potential alternatives utilities may source network services using pricing, programs, or procurement. For example, targeting the peak demand reduction capability of smart thermostats to reduce grid peak loads and eliminate the need for grid or substation upgrades.

- Meaningful Stakeholder Engagement

Establishing open and, transparent engaging among stakeholders. Information sharing, producing long-term relationship and consensus building processes can provide many advantages [8].

***Table 2**: Summary of planning considerations for traditional distribution planning and in the context of active distribution networks[9].*

	Conventional Network	***Active Distribution Network***
Degree of automation	- Very little or none	- Ubiquitous
Control philosophy	- Local control	- İntegrated - Hierarchical
Planning metrics	- Capacity requirements - System loads - Short-circuit level	- Capacity requirements - System losses - Energy conversation - DG Curtailment - Short-circuit levels
Planning options	- Phase balancing	- Phase balancing - Peak load management measurement - Addition of storage
Modelling DER	- If relevant, synchronous machine model	- Multiple DG types - Accurate short-circuit model - Energy forecasts - Various control modes
Demand side integration	- If relevant, contribution of large customers to system peak	- Multiple participation classes - Probabilistic or behavior-based models
Screening tools	- Not applicable	- Required to identified networks where detail studies are required
Reliability	- Rules of thumb	- Numerous potential points of failure (both network equipment and DER) - Need for detailed models, integrated with other analyses
Modelling communication networks	- Not applicable	- Analysis required to assess the dependence of different Applications on telecom performance
Advanced distribution applications	- Not applicable	- Quantify benefits and build business cases - Ability to analyze many applications in parallel

4. The Effect of Distributed Energy Resources on ADS

Distributed energy resource (DER) refers to “any resource located on the distribution system, any subsystem thereof or behind a customer meter”, which may include, but not limited to, “electric storage resources, distributed generation, demand response, energy efficiency, thermal storage, and electric vehicles and their supply equipment” (FERC 2020b)[10]. Up to now, these technologies have provided individual benefits to the end-use customers who own them. U.S. Federal Energy Regulatory Commission (FERC) Order No. 2222.

The distribution of DERs, especially distributed solar photovoltaics (PV), has grown rapidly in Turkey. At the end of 2021, the total installed PV is 7,916 Megawatts[7].

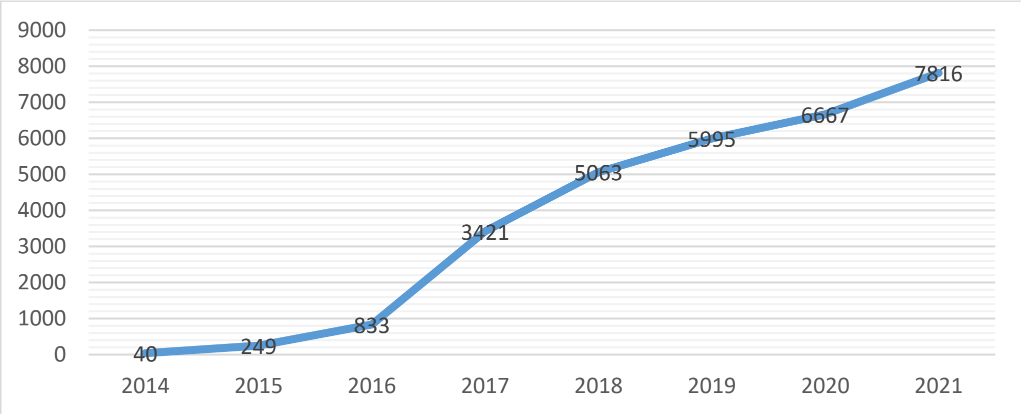

***Figure 2**: Distribution of photovoltaic plants in operation by years (MW).*

***Table 2**: Distribution of Unlicensed Generation Plants by Sources (MWe-%).*

Resource Type	***2020***		***2021***	
	Installed Capacity (MWe)	**Share (%)**	**Installed Capacity (MWe)**	**Share (%)**
Solar	6.257,61	91,71	6.907,78	91,53
Natural Gas	402,67	5,90	463,05	6,14
Biomass	83,71	1,23	89,11	1,18
Wind	70,83	1,04	73,08	0,97
Hydraulic	8,65	0,13	13,98	0,19
Total	**6.823,47**	**100,00**	**7.546,99**	**100,00**

***Table 3**: Distribution of Unlicensed Electricity Production by Resources (MWh-%).*

Resource Type	**2020**		**2021**	
	Energy supplied to the system (MWh)	**Share (%)**	**Energy supplied to the system (MWh)**	**Share (%)**
Solar	10.825.501,82	96,27	11.546.355,03	96,62
Biomass	273.446,13	2,43	250.861,61	2,10
Wind	119.466,89	1,06	118.935,99	1,00
Hydraulic	27.066,66	0,24	34.111,11	0,29
Grand Total	**11.245.481,50**	**100,00**	**11.950.263,73**	**100,00**

Variable renewable energy at higher powers will increase both the power system flexibility that DERs can provide and the need for ancillary services[11].

DERs can reduce net load density, renewable energy outages, and intensity and cycle for natural gas combined cycle power plants through energy exchange, which can lead to overall system operational cost savings.

Distributed storage, demand response, and other DERs can manipulate or modulate the load to provide ancillary services required to maintain power quality, reliability, and security.
In a future where more transportation, buildings and industrial loads are electrified, DERs will play a greater role in increasing existing capacity and replacing fossil fuel producers to provide energy system flexibility and ancillary services, leading to significant carbon emission reductions[1].
New market rules are needed to ensure the effective deployment and control of DERs to meet changes in the balance of supply and demand and provide rapid response to maintain grid stability and reliability. Under such rules, DERs can contribute to the system's ability to cope with external shocks such as extreme weather events, thereby increasing grid reliability.

5. Connection Standards of DERs to The System

DERs can cause voltage disturbances in the power system because of flexible demand and unbalanced resources. However, when DERs are equipped with advanced inverters, they can provide significant advantages to not only transmission and distribution systems, but also enhanced voltage regulation modes can allow DERs to accommodate potential new capacity in the grid. Advanced voltage and frequency switching capabilities allow DERs to connect with grid and continue to support the grid even during grid failures. The IEEE 1547-2018 standard is designed to both address utility concerns related to voltage problems and autonomous voltage regulation e.g., the ability to pass through voltage disturbances, adopted and implemented by only a limited number of governments[12].

6. Integration Between Transmission System and Distribution System

A more integrated approach to distribution planning, interconnection and operations. Power generation, storage and other sensitive loads connected to electric vehicles and distribution systems provide a number of electrical system advantages[13].
But realizing these advantages will require closer consideration between electricity distribution and transmission systems.
If actual system planners don’t recognize these advantages, electrical systems will risk being over- or under-constructed and become increasingly difficult to operate, leading to higher costs and potentially lower reliability.
Underestimation of DERs growth can result in over-construction of the transmission system, not just the distribution system, and excessive bulk generation capacity, resulting in increased system costs. Conversely, overestimating DERs can give rise to under-construction of transmission infrastructure and power outage issues.

7. Wholesale Marketing Effect

Regulatory frameworks and market rules to support the integration of DERs into wholesale markets are still in the early stages. Distributed generation operators, which emerged with the liberalization of the electricity market, have become important participants in the electricity market in many countries[14]. Moving towards a more comprehensive grid will require better integration of DERs into wholesale markets, distribution system operations as well as enhanced data availability. However, it should adapt more quickly to the changing structure in the regulatory legislation and related market rules[13].
Distribution system planners will need to take into account the temporal variability, quantities, locations, operational uncertainty, operation and penetration of DERs and loads in their forecasts.

8. Opinions of The Countries Trying to Apply to ADS

The CIGRE C6.11 working group global survey (involving 27 utilities and research bodies worldwide such as Australia, Denmark, the Netherlands, Spain and the UK) on the planning and operation of active distribution networks also made a SWOT analysis of the advantages and disadvantages of the active distribution planning system compared to traditional planning[11].
According to this analysis;

Strengths;

- ✓ Economical alternative to network reinforcement
- ✓ Increased operational reliability, including power delivery
- ✓ Electricity loss reduction
- ✓ Automation and control providing enhanced network access for DG/load customers

Weaknesses;

- ✓ Maintenance issues
- ✓ Lack of current experience
- ✓ Distribution companies are not incentivized to take risks.
- ✓ Existing communication infrastructure

Opportunities;

- ✓ Distribution network equipment that has reached the end of its economic life could be replaced with active capable equipment.
- ✓ Development and implementation of smart metering technologies
- ✓ Development of communication infrastructure
- ✓ Moving towards a low carbon economy through the deployment of distributed renewable energy sources

Threats;

- ✓ Regulatory issues hinder the development of active distribution networks
- ✓ DG continues to grow in size and is connected to the transmission network
- ✓ Information security on the communication infrastructure
- ✓ Active networks are not compatible with existing passive networks.

9. Development of The ADS Planning Model

Distribution planning, connection to the system and network operating system are three main topics within distribution grid services. Throughout historically, most of the distribution companies do not plan for DER focused network improvement; instead, it is usually planned to accommodate the consumer-induced load increase. Requires distribution companies to integrate DER forecasts into their distribution investment planning, including integrating DERs in load forecasting and creating hosting capacity maps, to better anticipate longer-term distribution investment needs and facilitate the development of DERs. Distribution planning, system connectivity and closer integration between operations will help improve all three processes[5].
Better integration consists of incorporating information from distribution planning to system connection remote monitoring and system operations. Figure 3 shows some (if not all) of the information that can be shared between these functions to enable more efficient integration[13].

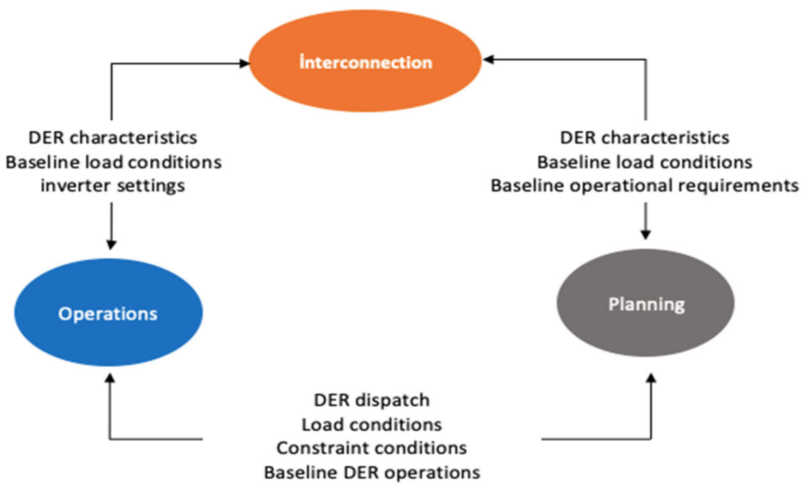

***Figure 3**: İnformation Sharing Among Distribution Interconnection, Planning and Operations.*

There are studies on many ADS planning models in the literature reviews. However , not all issues related to ADS planning have been comprehensively addressed. For example, most researchers have not been able to fully integrate

ESSs into ADSs. Generally, the operational issues of ESSs are taken into account, but the optimal functioning of ESSs in the system is ignored.[4].
Recommendations in the field of ADS planning methods and research prospect, with several notable results[4].

- Environmental issues cause long-term or short-term temporal variability. In other words, weather can impact ADS planning model. Seasonal load or generation can create unstable grid, and so needs further investigation in terms of optimization target and decision variable.
- Probabilistic multi-scenario-based approaches and multi-level programming, high-level uncertainties, incorporating operational aspects into the planning model, integrating energy storage facilities and DG, and addressing key issues related to ways to deal with multiple time scales are recommended approaches.

10. Conclusion

Nowadays, many countries are facing a significant increase in the connection of DERs to the system and it is obvious that the demand will increase.
It is not too late for relevant association in countries to take the necessary steps to build the new systems needed for Active Distribution Planning.
In our country, this issue was mentioned by EMRA in Turkey smart grid 2023 vision and strategy roadmap summary report. However, traditional investment planning methods are used in practice[15].
Distribution companies and the electricity market can benefit from an Active investment planning method that fully understands its value and provides direction for its distribution by optimizing the distribution grid planning, the allocation of distributed generation facilities, energy storage facilities and EV charging stations in collaboration, taking into account the different perspectives of multiple stakeholders[16].

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